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The Extrasolar Planet Imager (ESPI)

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Abstract. ESPI has been proposed for direct imaging and spectral analysis of giant planets orbiting solar-type stars. ESPI extends the concept suggested by Nisenson and Papaliolios (2001) for a square aperture apodized telescope that has sufficient dynamic range to directly detect extrasolar planets. With a 1.5-meter square mirror, ESPI can deliver high dynamic range imagery as close as 0.3 arcseconds to bright sources, permitting a sensitive search for extrasolar planets around nearby stars and a study of their characteristics in reflected light.

1. Introduction

Since the first detection of a planet orbiting another star, the presence of more than 100 other extrasolar planets has been inferred from the small reflex motions that they gravitationally induce on the star they orbit; these result in small, but detectable, periodic wavelength shifts in the stellar spectrum. Radial velocity favors the detection of massive, Jupiter-class objects orbiting close to the star, leaving open the question of whether the architecture of our solar system in which the giant planets occupy orbits $\geq$ 5 AU from the star is common or rare. This distinction is important since it is believed that giant planets cannot form close to a star and must spiral in from a much more distant radius, disrupting the stable orbits of any terrestrial planets in their path. In this way, the arrangement of giant planets around a star is related to the probability that that star harbors Earth-like planets in stable orbits at radii that allow for the presence of liquid water and possibly life.

2. ESPI Scientific Objectives

The scientific objective of the baseline 3-year ESPI mission is to directly image and characterize extrasolar giant planets in $\geq$ 5 AU-radius orbits around 160-175 candidate stars, all of which are brighter than apparent magnitude V = 8 and lie within 16 parsecs of Earth; five of the nearest stars also offer an opportunity for detecting terrestrial-type planets. As shown in Figure 1, ESPI will successfully image planets whose orbital periods range up to 30 years, providing unique access to the outer regions of extrasolar planetary systems.

Most of these systems could be observed in 18 months, leaving 18 months for follow-up studies to confirm common proper motion (used to distinguish a planet from a chance background source) and to fit partial orbits to derive orbital parameters (in conjunction with precise radial velocity measurements). ESPI will also obtain spectroscopic and photometric measurements of several of the brightest planets found.

A variety of different conditions and chemical processes in the atmospheres of extrasolar planets is anticipated, making spectroscopy in the 5000 to 10,000 $\mathring{A}$ region essential, even if only a handful of the ESPI-discovered planets are sufficiently bright to permit it. If Jupiter-like planets with orbital radii $\geq$ 5 AU are common, the ESPI mission may yield two or three dozen detections of planets toward which filter spectrophotometry should be possible, and a further dozen with sufficient signal-to-noise ratios, SNR, to permit low resolution ($\lambda/\Delta\lambda \leq 40$) spectroscopy at SNR $\sim$ 8 to 9. Even these limited capabilities will permit ESPI to distinguish the albedo of planets with spectra similar to that of Jupiter, as contrasted to Uranus. The methane band at 9000 $\mathring{A}$ and the continuum break between Jupiter-like gas giants and Uranus-like ice giants near 6000 $\mathring{A}$ are clearly detectable.

3. Technical Approach

ESPI uses an Apodized Square Aperture (ASA) to achieve the high dynamic range required for extrasolar planet imaging. The ESPI optical design em-

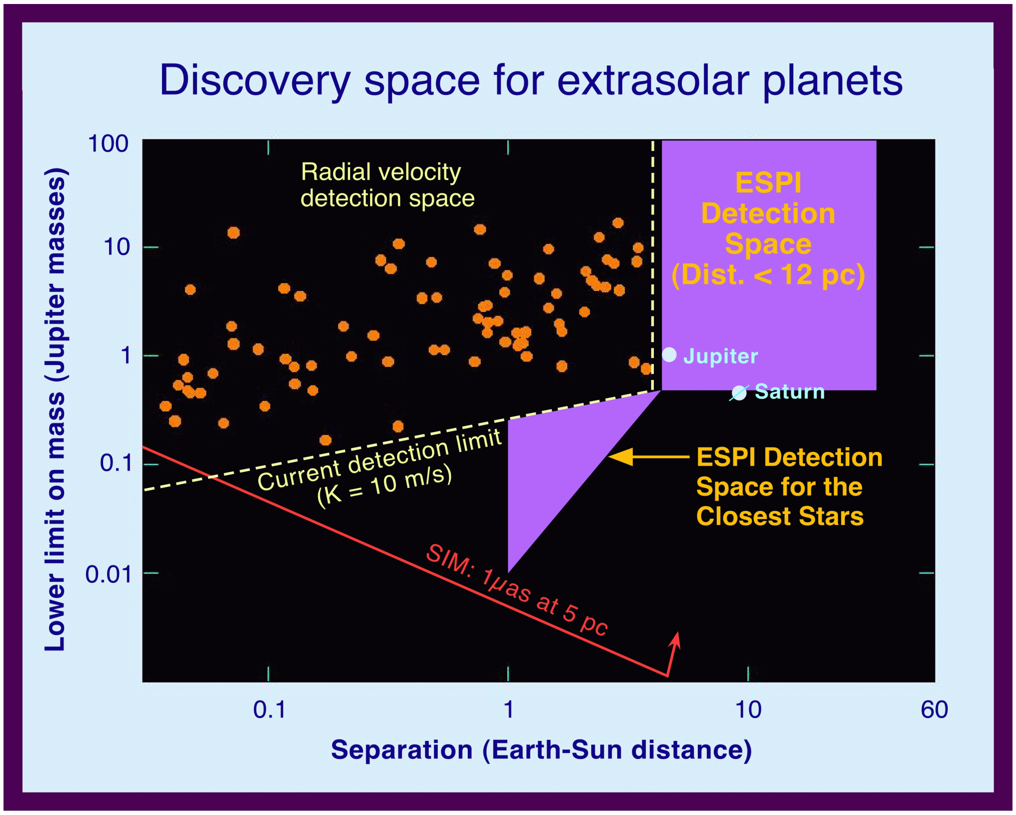

Figure 1. Discovery Space for ESPI

ploys an unobscured primary mirror in an off-axis cassegrain configuration. An ASA transmission mask is located close to the focal plane along with a coronagraphic blocker at the focus. The ASA mask has the form of the product of two crossed prolate spheroidal (PS) functions. The PS functions are chosen to minimize diffraction close to the central peak and to maximize overall transmission through the mask (Papoulis, 1986). The ASA technique is described in detail in Nisenson and Papaliolios (2001).

Figure 2 shows (a) Cuts through two versions of prolate spheroid apodization functions. (b) Three point spread functions from PS apodization adjusted for different throughputs and diffraction suppression: 48% (top), 33% (middle), and 23% (bottom). (c) Effect of random transmission errors on the point spread function (PSF). (d) Effect of random phase errors (flat spectrum at mid-frequencies, $1/f^2$ at higher frequencies). In panels b, c, and d, off-diagonal separations of $\pm 3\lambda/D$ are shown with vertical dashed lines.

The ESPI dynamic range will be limited by scattered light from the optical surfaces, not diffraction. Figure 3 is a result of an accurate computer simulation showing how ESPI could detect planetary systems: (a) The PS apodized aperture. (b) Two giant planets as seen with ESPI (no wavefront aberration) from 10 pc with the inner planet 1/2 Jupiter diameter and 2.5 AU from star and the outer planet 1 Jupiter at 5 AU from star. Note the suppression of diffraction

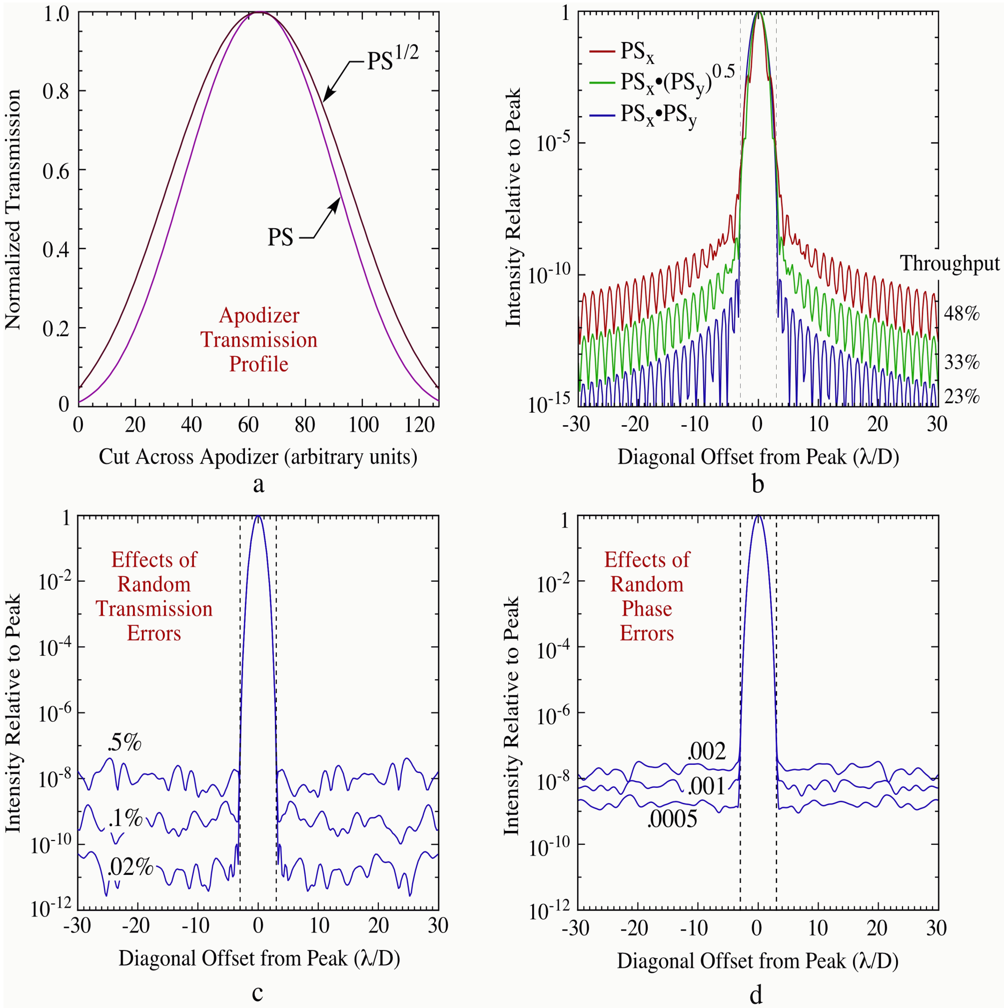

Figure 2. Apodizing Functions and PSF's for ESPI

everywhere except along the central cross (which is blocked). (c) ESPI image with 1/1000 wave optical quality for 5th magnitude star, 1 hour integration. (d) Image after subtraction of a field with no planets. For spectroscopy, rotation of the telescope allows locating a dark speckle in the position of the planet, improving the signal-to-noise ratio of the observation.

We have also tested the ESPI apodization approach in the laboratory. Using pairs of point sources and a superpolished imaging mirror, we have demonstrated detecting contrasts of 3×10^9 between the "star" and a "planet" separated by $6\lambda/D$ is possible.

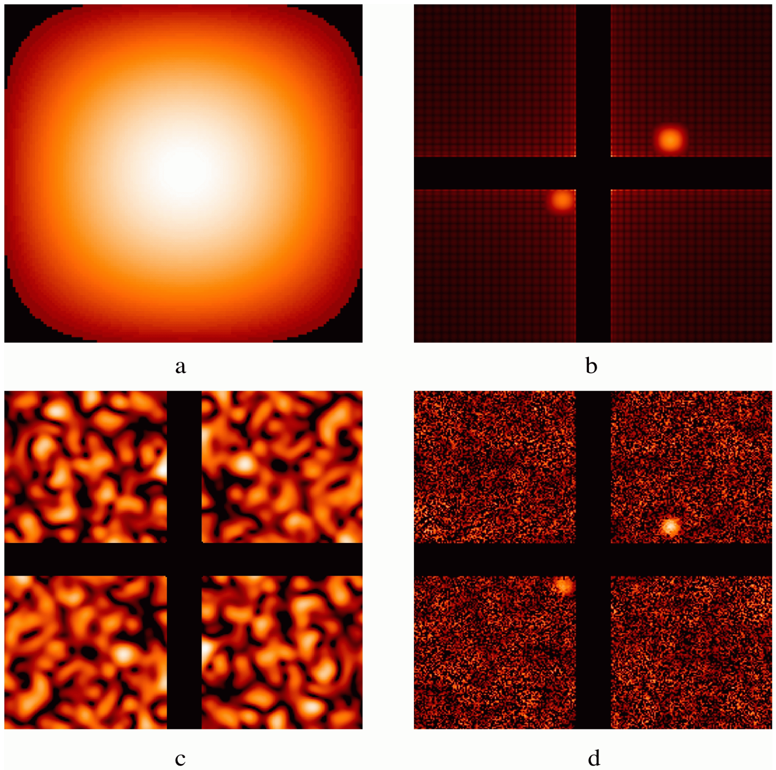

Figure 3. Simulation of ESPI Planet Detection

4. Summary

ESPI has been proposed for direct imaging and spectral analysis of giant planets orbiting solar-type stars. It also permits unique observations of many Galactic, extragalactic and cosmological sources. ESPI has an off-axis cassegrain design with a square telescope mirror. The apodization mask is located near the telescope focus and is optimized for transmission and for the narrowness of the central peak of the PSF, since this sets the angular resolution of the system. ESPI would be capable of detecting Jupiter-like planets in relatively long-period orbits around as many as 160 to 175 stars with a signal-to-noise ratio ≥ 5. In addition to the survey, ESPI will also study a few of the brightest discovered planets spectroscopically and spectro-photometrically to distinguish ice giants like Uranus and Neptune from gas giants like Jupiter and Saturn, and to determine whether super-Earth and super-Venus planets exist.

References

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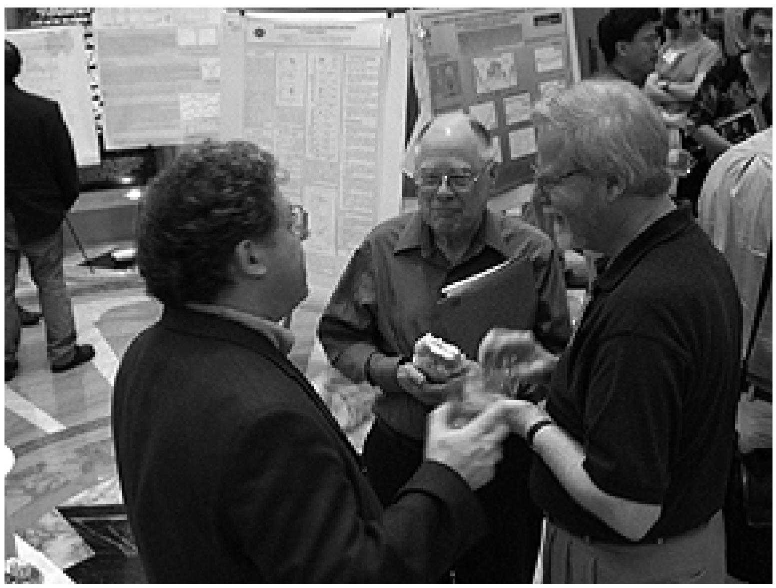

The Poster Session